Initial Investigation of Petroleum Systems of the Permian Basin, USA

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Presentation Outline

• Goals of the study
• Geologic summary
• Analytical methods
• Definition and distribution of oil types
• Biodegradation
• Mixing of oils
• Conclusions

Goals of this Study

• Provide geochemical input for the USGS Permian Basin oil and gas assessment project
• Provide state-of-the-art geochemical data on Permian Basin petroleum systems
• Perform oil inversion study to characterize source rocks (in the absence of correlation for all sources)
• Confirm previous assessments of the Permian Basin petroleum systems
Permian Basin Production History

Cumulative Oil: 34.9 Billion barrels
Cumulative Gas: 98.5 Trillion cubic feet
Total Wells Drilled: 131,950
Active Wells: 107,098
First Production: 1905

Location of the Permian Basin
Structural Elements of the Permian Basin

Permian Basin Cross Section
Permian Basin Oils Samples Used in this Study

300+ Oils
Source Rocks
• Simpson
• Barnett
• Bone Springs
Analytical Approach

- Carbon isotopes (saturated and aromatic HC)
- Sulfur Content
- High-resolution gas chromatography (GC) of oils and rock extracts
- Biomarker analysis (GCMS)

Permian Basin Oil Families

- Permian Leonardian Bone Springs
  - Upper (Shale and carbonate)
  - Lower (Carbonate)
- Permian Guadalupe
- Permian Wolfcamp
- Pennsylvanian?
- Mississippian Barnett Shale
- Devonian-Mississippian Woodford Shale
- Ordovician Simpson Formation
Stable carbon isotopes of Permian Basin oils are variable

Sulfur content of Permian Basin oils implies variable source facies
**Biological Marker (biomarkers):**

**Terpane Ion Chromatograms**

**Marine shale source:**
- High tricyclics
- e.g., Woodford

**G. prisca source:**
- low tricyclics
- Ordovician

**Carbonate source:**
- High $C_{29}$ hopane
- Predom. $C_{35}$ hopane
- e.g., Bone Springs

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**Biomarker Ratios**

**Terpanes (m/z 191)**
- C19t/C23t
- C22t/C21t
- C22t/C24t
- C24t/C23t
- C26t/C25t
- C24Tet/C23t
- C24Tet/C26t
- C23t/C30H
- C24Tet/C30H
- Gam/C30H
- Gam/C31HR
- C32 S/(S+R)

**Steranes (m/z 217)**
- C27 aaa 20R
- C28 aaa 20R
- C29 aaa 20R
- C27 Dia/(Dia+Reg)
- (C21+C22)/(C27+C28+C29)
- C29 abb/(aaa+abb)
- C29 aaa 20S/20R
- C29 aaa 20S/(S+R)

**αββ-Steranes (m/z 218)**
- C27 abb 20(R+S)
- C28 abb 20(R+S)
- C29 abb 20(R+S)
- C29/C27 abb Sterane Ratio

**Other Ratios**
- Tricyclic/Pentacyclic Terpanes
- Steranes/Terpanes
Differentiation of Permian Basin Shales

Steranes
\[ \%27 / \%28 / \%29 \]

Bone Springs
\[ 45 / 19 / 36 \]

Wolfcamp
\[ 53 / 19 / 28 \]

Pennsylvanian
\[ 40 / 19 / 41 \]

Differentiation of Permian Basin Carbonate

Bone Springs D
\[ \delta^{13}C_{\text{sat}} -27.5 - -28.5 \]

Guadalupe
\[ \delta^{13}C_{\text{sat}} -29.0 - -30.0 \]
Permian Oils Overlay on Williston Basin
Type-specific Oils

Confirmation of Light Hydrocarbon Inference

Sample 041 T2-164 TOKIO, S - WOLFCAMP Ion mass 1
Shale-sourced Oil Hopane Biomarkers

Classical *G. prisca* Fingerprint
Carbonate biomarkers with shale C7 light hydrocarbons

Sample 022 N5-58 HOBBS, E - SAN ANDRES Ion mass 191.20
Sample 027 N5-67 HOUSE - SAN ANDRES Ion mass 191.20
Sample 042 T2-165 - DEVONIAN Ion mass 191.20

but...
Carbonate with high Tricyclics

Mississippian Barnett Source Rock C₇ Distribution

Note: Source rocks with mixed or gas potential will plot with carbonates; use Pr/Ph to segregate.
Permian Basin Oil Families

Distribution of Ordovician Simpson Sourced Oils

\(\% S = 0.3 - 0.5\)

\(\delta^{13}C_{\text{Sat}} = -32.5 - 34.5\)

\(\delta^{13}C_{\text{Aro}} = -32.4 - 34.0\)

Pr/Phy = 0.5 – 1.0
Distribution of Devonian Woodford Oils

- \%S = 0.3 – 0.6
- \( \delta^{13}C_{\text{Sat}} = -29.5 – 30.5 \)
- \( \delta^{13}C_{\text{Aro}} = -28.5 – 29.9 \)
- \( \text{Pr/Phy} = 1.1 - 1.4 \)

Distribution of Barnett Sourced Oils

- \%S = 0.2 – 0.5
- \( \delta^{13}C_{\text{Sat}} = -29.0 - 30.0 \)
- \( \delta^{13}C_{\text{Aro}} = -28.5 - 29.5 \)
- \( \text{Pr/Phy} = 12. – 1.5 \)
Distribution of Pennsylvanian Sourced Oils

\[ \%S = 0.2 \text{ – } 0.6 \]
\[ \delta^{13}C_{\text{Sat}} = -29.0 \text{ - } -30.5 \]
\[ \delta^{13}C_{\text{Aro}} = -28.5 \text{ - } -30.0 \]
\[ \text{Pr/Phy} = 1.10 \text{ – } 1.35 \]

Distribution of Permian Wolfcamp Oils

\[ \%S = 0.2 \text{ – } 0.4 \]
\[ \delta^{13}C_{\text{Sat}} = -29.0 \text{ - } -30.0 \]
\[ \delta^{13}C_{\text{Aro}} = -28.5 \text{ - } -29.5 \]
\[ \text{Pr/Phy} = 1.2 \text{ – } 1.5 \]
**Distribution of Permian Guadalupe Oils**

- %S = 0.7 – 1.6
- δ$^{13}$C$_{Sat}$ = -29.0 - -30
- δ$^{13}$C$_{Aro}$ = -28.5 - -29.5
- Pr/Phy = 0.9 – 1.0

**Distribution of Permian Lower Bone Springs Oils**

- %S = 1.5 – 3.0
- δ$^{13}$C$_{Sat}$ = -29.0 – 29.5
- δ$^{13}$C$_{Aro}$ = -28.5 –29.0
- Pr/Phy = 0.9 - 95
**Distribution of Permian Upper Bone Springs Sourced Oils - Carbonate**

- %S = 1.5 – 3.0
- δ^{13}C_{Sat} = -26.5 – -27.5
- δ^{13}C_{Aro} = -26.0 – -27.0
- Pr/Phy = 0.60 – 0.85

**Distribution of Permian Upper Bone Springs Oils - Shale**

- %S = 0.05 – 0.3
- δ^{13}C_{Sat} = -28.0 – -29.5
- δ^{13}C_{Aro} = -28.0 – -29.0
- Pr/Phy = 1.5 – 1.8
Biodegraded or Mixed Oils

A multitude of oil types exist in the Permian Basin
Sources range from sulfur-rich carbonates, clay-rich marine shales, kukersites (G. prisca) algal kerogens
Barnett Shale - oil correlation demonstrated for first time in the Permian Basin
Ordovician Simpson Formation - oil correlation demonstrated
Many oils exhibit intermediate geochemical characteristics indicative of mixing
Biodegradation is a significant process in the Permian Basin
Variable generation rates are implied by the complexity of inferred source lithofacies from oil chemistry
The story is not complete